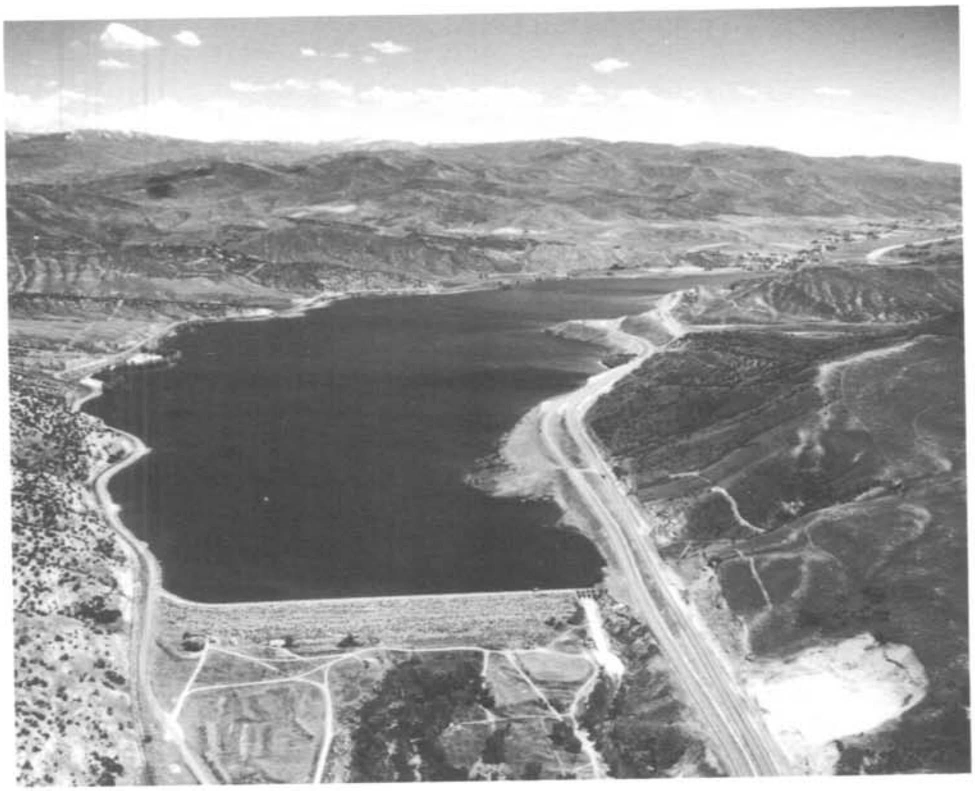
WATER OPERATION AND MAINTENANCE

BULLETIN NO. 146

December 1988



IN THIS ISSUE

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

The Water Operation and Maintenance Bulletin is published quarterly for the benefit of those operating water supply systems. Its principal purpose is to serve as a medium of exchanging information for use by Bureau personnel and water user groups for operating and maintaining project facilities.

While every attempt is made to ensure high-quality and accurate information, Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

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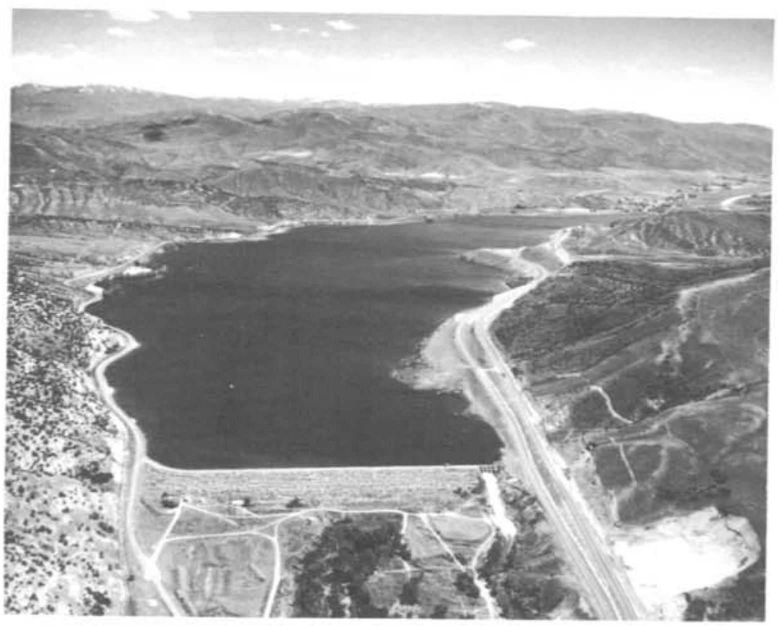

Cover photograph:

Echo Dam and Reservoir near Coalville, Utah, Weber River Project. 7/2/71

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COLD WEATHER TIPS FOR CONSTRUCTION EQUIPMENT[1]

Construction equipment needs special attention in cold weather to operate at optimum productivity. Moisture can cause costly and possibly irreversible damage to equipment at freezing temperatures.

Precautions taken before and during the winter season will help ensure that construction equipment operates properly in cold weather.

Several precautions should be taken before and during the winter to help ensure that equipment will operate properly in cold weather, according to John Strangberg, field service training manager for J. I. Case, Racine, Wisconsin.

Pre-Season Check.–A proper maintenance schedule should include a change of transmission fluid, engine oil, and coolant at the start of cold weather. Fluids that have been used too many hours or left in the machine too many months are less able to provide the protection needed when the temperature drops to the freezing level. A machine's systems and parts are much more sensitive in winter than in warmer seasons because fluids tend to move more slowly when cold, taking longer to reach equipment parts.

Use a transmission fluid that absorbs and minimizes the effects of moisture resulting from cold weather condensation. Unabsorbed water can freeze, promote rust, reduce output of pumps, clog filters, and cause premature deterioration of machine parts. Use high-quality gasoline or diesel fuel. For diesel engines, use a fuel with a cloud point of at least 10 °F below the lowest anticipated temperature to prevent diesel fuel waxes from forming and plugging filters. The fuel should be a winterized grade 2-D meeting ASTM D-975 specifications.

Check the operator's manual to be sure that the engine oil is the correct viscosity for low-temperature operation. Newer engines use a multi-grade oil that does not require

[1] Reprinted with permission from the Editor, Public Works, July 1988 issue.

a viscosity change for cold weather use. Older engines require seasonal changes of oil that should be part of the machine's normal maintenance schedule.

Use a coolant low in silicates and a high-quality water low in minerals, chlorides, and sulfates. Mix the water with ethylene glycol, varying the amounts of each as required by the lowest anticipated temperature. Maintain the ethylene glycol concentrate at about 50 percent, which will provide protection to -34 °F. Never let it exceed 65 percent or fall below 45 percent because the additives in the antifreeze will not protect properly outside those limits.

Cold Weather Starting.–Keep the battery at full charge. Cold weather and thickened engine and transmission oil greatly increase cranking power requirements on a battery. Also, the electrolyte in a badly discharged battery can freeze in extremely cold temperatures.

A local dealer can supply starting aids, such as engine block, oil pan, battery, and coolant heaters. Strangberg does not recommend the dipstick heater because the heat is so localized that additives in the oil can be burned in one spot, while the rest of the oil is insufficiently heated. Use ether starting fluid only when the ether dosage can be controlled by an attachment mounted directly on the engine.

Cold Weather Operation.–Always heat the hydraulic transmission fluid to operating temperature by running the engine at 1,500 r/min for about 5 minutes before operating the machine. Operating a machine with cold transmission fluid can cause erratic or rough operation.

During cold temperatures, the engine may not warm up to or maintain the rated operating temperatures at slow engine speeds. When the engine is operated below 1,500 r/min, incomplete combustion may result. Before stopping the engine after heavy, sustained loading, run it at slow speed for 3 to 5 minutes to allow a gradual decrease of engine temperature and prevent excessive condensation.

At day's end, fill the fuel tank to prevent condensation from forming in the tank. Remove water from the water trap each day or damage to precision fuel injection parts will occur.

Park the machine on a hard, level surface, out of mud or water that can freeze the tires or tracks to the ground. Then cover the end of the exhaust pipe to prevent moisture from entering. If the machine is to be stored for a long period of time, jack up the machine to alleviate the load on and prevent "flattening" of the tires.

Cold Weather Dangers.–Never use gasoline or diesel fuel to reduce the viscosity of engine oil. Not only does fuel adversely affect the protective value of the oil, it creates a fire hazard when operating the engine. Never add gasoline or alcohol to diesel fuel. The mixture creates a vapor that is extremely explosive. Have the transmission fluid analyzed for water contamination at regular intervals. Fluid with over one-half percent water, by volume, does not absorb condensation effectively and increases the chance of premature deterioration of machine parts.

When storing equipment for long periods of time during cold weather, drain and replace the engine oil and coolant. Do not store a machine without oil in it so that, in an emergency situation, the machine will be operational.

"The performance and life of construction equipment are dependent on proper maintenance year-round," says Strangberg. "In freezing temperatures, just a few simple precautions can protect expensive machinery from premature wear and failure."

PHYSIOLOGICAL INVESTIGATIONS OF HYDRILLA

An Obnoxious Aquatic Weed

by Joan S. Thullen[1]

There are hundreds of thousands of miles of canals and waterways in the West. A majority of these water systems are plagued by a dilemma little known or understood by the average citizen. Annually, aquatic weeds create problems requiring expenditures well into millions of dollars for weed control. Research is currently underway to study the pattern of weed growth in waterways and to determine methods of controlling this aquatic menace which limits and obstructs waterflow.

Hydrilla (*Hydrilla verticillata*) is now well known throughout the warmer climates of the United States as a noxious aquatic weed which can, once it has infested a water body, clog waterways and reservoirs by its rapid growth and ability to adapt and proliferate even in extremely unfavorable conditions [1-6][2]. The numerous structures for reproducing itself include stem fragments, tubers (potato-like reproductive structures borne in the soil at the ends of rhizomes), axillary turions (buds borne where the leaves attach to the stem capable of producing a new plant after dropping to the ground), seeds, stolons, and rhizomes. The physiological mechanisms which produce each of these structures have yet to be fully understood.

Ongoing investigations in the Environmental Sciences Section attempt to pinpoint hydrilla's specific physiological responses to several different conditions. This information is necessary to fully understand the physiology of hydrilla, especially its reproduction, so more effective and less costly methods of control can be developed.

The investigations discussed here primarily evaluated tuber formation and tuber germination.

Investigations were performed in the laboratory using environmental growth chambers and incubators to regulate light, temperature, and day length as well as various atmospheric gasses including oxygen (O_2), carbon dioxide (CO_2), and air. Fresh hydrilla plants used in the studies came from canals in the Imperial Valley of southern California.

Results have shown that CO_2 at levels between 15 and 56 mL/min is toxic to hydrilla and restricts tuber production. Out of 12 subsamples, only 1 tuber was formed in two 24-week periods [7 and 8]. Hydrilla plants which produced the most tubers were plants which were aerated or oxygenated, especially those aerated. Plant material biomass was also significantly greater than those given CO_2 (4 to 3.3 times greater).

Aerated hydrilla sprigs grown in continuous fall-like conditions (warm, yet short, days and nights) produced the greatest numbers of tubers. More tubers were formed in the longer fall-like conditions. After 24 weeks, the maximum mean number of tubers produced per square meter was 2,145 [8].

[1] Joan S. Thullen is a Botanist employed by the Bureau of Reclamation's Denver Office, Denver, Colorado 80225.
[2] Numbers in brackets refer to literature cited at end of report.

Data from preliminary investigations indicate that maintaining hydrilla in a cropped condition, as from fish feeding, may discourage tuber formation. Physiologically, this makes sense since plants must be able to make food (by converting light, oxygen, and water into sugars) before they can store it. Occasional fish feeding could have extremely different effects on tuber production and is an area where more research is needed.

Once the hydrilla plants formed tubers, they were harvested and studied for their germination characteristics. It is well documented that hydrilla tubers can remain in the soil for up to 10 years before conditions are right for them to germinate. Under ideal laboratory conditions, some tubers germinate within a few days, while other tubers will not have germinated after 6 months. Several vernalization techniques were investigated to determine what condition has to be met before germination occurs.

Vernalization is any kind of treatment of a seed, bulb, or tuber which hastens fruiting or germination. Numerous studies have been done in the Environmental Sciences Section to evaluate effects of cold temperatures on tuber germination. Results have shown that longer initial vernalization periods did not improve tuber germination, but additional periods of vernalization improved germination significantly. It is not known why some tubers will germinate almost immediately and why others in the laboratory require up to three vernalization treatments and 24 weeks after being harvested before they will germinate. Perhaps this could be an additional strategy used by hydrilla to ensure its survival regardless of the environmental conditions.

Although these results are preliminary, an understanding about hydrilla's physiology is becoming clearer. By applying some of this knowledge, less costly and more practical methods may be developed for restricting this noxious weed. Possible areas which could be investigated further to control tubers are methods to reduce the oxygen available for their formation (e.g., administering toxic levels of carbon dioxide) or methods to encourage tuber germination with a subsequent treatment to kill the young plants at a vulnerable time. Research will be continued in these and other areas.

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Figure 1. - A lateral canal is clogged with hydrilla which severely restricts the waterflow.

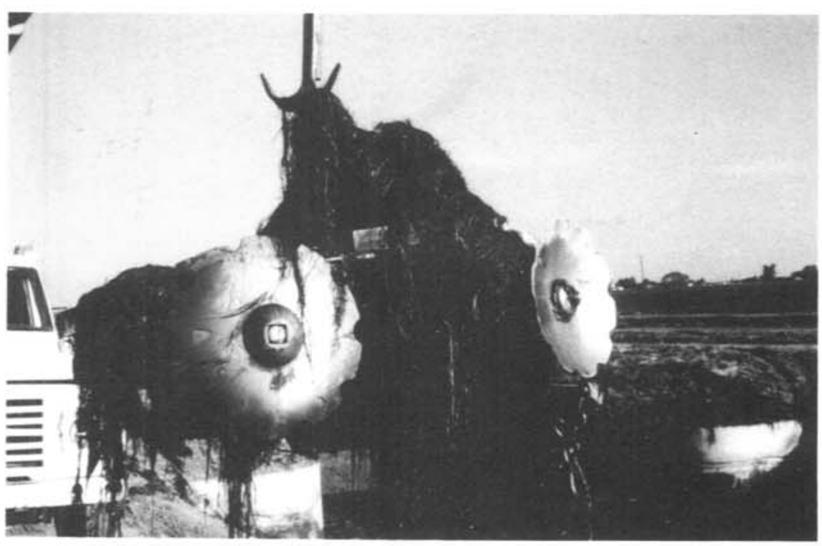


Figure 2. - During maintenance operations, large amounts of hydrilla are removed in order to allow water to be delivered.

Figure 3. - These hydrilla tubers and turions (second from left) enable the weed to survive long winters or dry periods. The tuber on the left has germinated (ruler in millimeters).

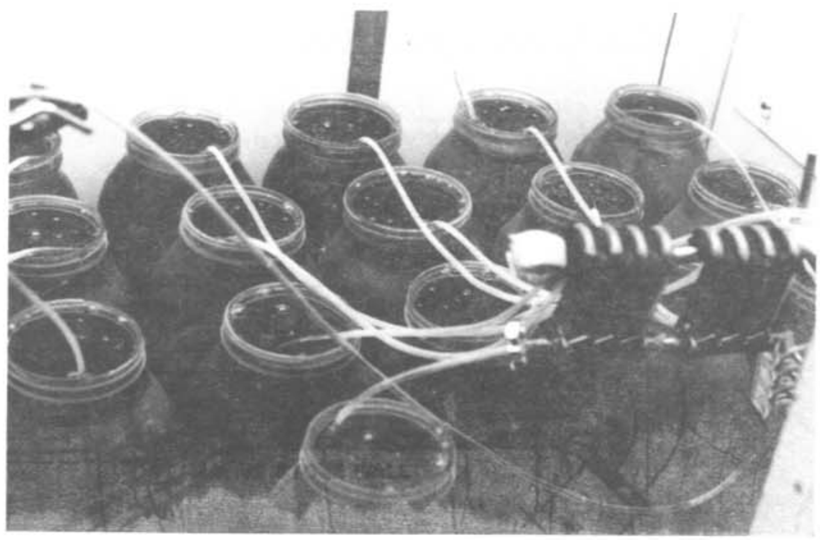


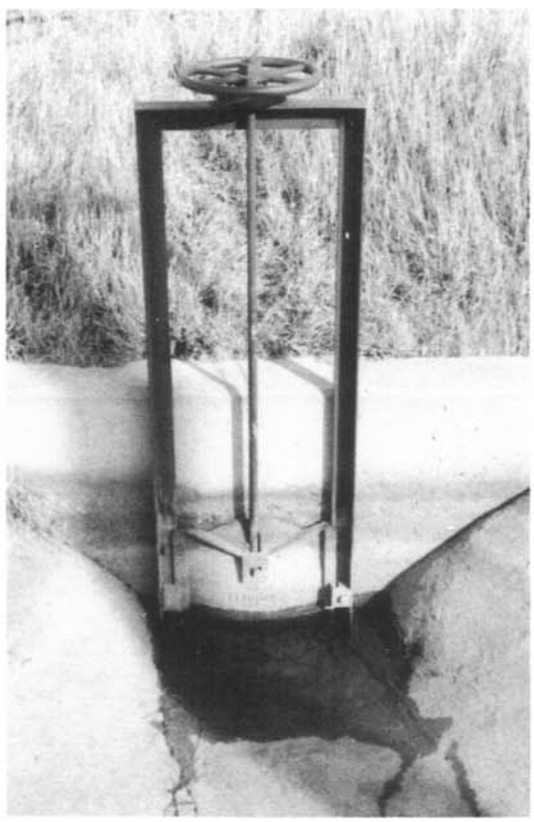
Figure 4. - Air is being bubbled into each test jar.

LEAKY GATES[1]

Two-Year Research Study Underway

Leaking turnout gates can be a nagging headache for farmers and ditchriders. Seepage through poorly sealed gates causes problems with trafficability in nearby fields, increased weed growth, soil degradation, reduced crop yields, and a needless loss of valuable water. A recent report by Associated Engineering Alberta Ltd., for the Irrigation Branch of Alberta Agriculture, has attempted to assess the severity of the problem of leaky turnout gates and proposes some viable solutions to minimize leakage.

To determine the severity of the problem, 16 gates (including Lethiron, Armco, and Whipps brands) ranging from 450 to 1200 mm (18 to 48 inches) in diameter and 1 to 34 years in age, were investigated. All of the gates were situated along main laterals in the Raymond Irrigation District. To determine the rate of leakage, the gates were closed and the downstream side was drained. The water level upstream of the gate was raised to its maximum level and the leakage through the gate was measured using a small pump and a measuring vessel.



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Leakage rates were found to vary from a high of 1.035 L/s (1.65 gal/min) to a low of 0.009 L/s (0.02 gal/min), with an average rate of 0.3 L/s (0.48 gal/min). Reasons for the leakage included debris buildup, weed growth, silt, improper adjustment, and corrosion or gouging of the seating faces. Leakage rates were not wholly dependent on age, since a 34-year old Lethiron gate produced the least leakage of all the gates studied.

One proposal calls for the installation of scrapers to clean the seats when the gate is opened or closed. One wiper would be mounted on the gate frame to scrape the slide face, and another wiper mounted on the bottom of the slide would scrape the thimble seat face. Another solution could be the addition of a lever arm on the gate frame. The lever would be attached to the slide and pass through a fulcrum point above the slide, allowing this operation to exert additional pressure on the gate face and thereby produce better seat contact. However, reducing leakage can be as simple as properly adjusting the wedges so that the slide settles evenly on them, or thoroughly cleaning debris from the inlet so that it will not be caught between the seat faces.

Although it is easy to disregard a small trickle of water leaking through a gate, consider these numbers: a 0.3 L/s (0.48 gal/min) flow over a 163-day irrigation season translates into 4225 m^3 (3.43 acre-feet) of water. If the estimated 9,000 turnout gates in use in southern Alberta are shut and leaking for 30 percent of the irrigation season, 11,407,500 m^3 - approximately 9,250 acre-feet - of valuable water is trickling away each year.

Funding for the continuance of this research study in 1988-89 has been provided by Farming For the Future. Associated Engineering will return to the original study area in 1988 to further monitor the gates and implement some gate improvements. Hopefully some viable solutions can be found for this often ignored waste of water.

For more information, please contact Svat Jonas, P. Eng., Irrigation Branch, Alberta Agriculture, Agriculture Centre, Lethbridge, Alberta, T1J 4C7. Telephone (403) 381-5164.

GUIDELINES FOR TESTING GATES AND VALVES AT MAJOR FACILITIES

These guidelines were issued originally Bureau-wide on August 14, 1987, from the Denver Office to establish consistency during Review of Operation and Maintenance Program examinations of major facilities.

These guidelines can also assist personnel in ensuring all gates and valves are performing properly and continue to perform properly. Following completion of any operational test, the results should be documented in the operating log for the facility. If, during any operational test, the gate or valve used will not open or close from any position or otherwise malfunctions, the test should be stopped and the cause of the malfunction determined and corrected. The responsible Bureau office should be contacted for assistance before further testing.

Verification of Gate/Valve Operations

When onsite examinations of dams and their appurtenant features are performed, the operational adequacy of the mechanical features of the spillway and outlet works should be determined. Ideally, during these examinations it is desirable to observe full operation of all equipment. However, because of conditions at the dam, such as valid downstream delivery requirements which cannot be interrupted for any reason, ongoing maintenance, damaging discharges, loss of water and power revenues, etc., testing and observation through the full range of operation is not always possible. Therefore, operating personnel should establish a gate/valve testing program, in conjunction with periodic examinations and in the interim time periods, to ensure the reliability of its equipment.

The frequency of testing gates and valves should be stated in the SOP (Standing Operating Procedures) for the facility. Regulating gates/valves should be given a full operation test at least annually with the downstream portion of the outlet works unwatered and also under flow conditions. For emergency (guard) gates/valves, an unbalanced head test is recommended at least once every 6 years and a balanced head test at least annually. However, UNBALANCED OPERATION OF OUTLET WORKS EMERGENCY (GUARD) GATES (WHEN ASSOCIATED WITH A PIPE DOWNSTREAM OF THE GATE) SHOULD NOT BE PERFORMED UNLESS THE PIPE DOWNSTREAM FROM THE GATE IS EQUIPPED WITH EITHER AN AIR INTAKE VENT OR AN AIR INLET AND AIR RELEASE VALVE THAT HAS BEEN SIZED AND APPROVED AND AN OPERATION TEST PROCEDURE HAS BEEN DEVELOPED FOR THE SPECIFIC INSTALLATION. The need and procedures for unbalanced testing will be determined and arranged separately, prior to the onsite examinations. In addition to established lubrication and maintenance frequencies, the equipment should be lubricated and any other needed maintenance performed prior to operational testing and exercising.

To the extent possible, the following procedures should be followed during onsite examinations.

a. Equipment operation should be discussed with appropriate operating personnel with sufficient lead time prior to the examination so that necessary arrangements can be made.

b. Any gate/valve operation performed during an examination should be in accordance with the facility's SOP and performed only by trained operators at the dam. Thus, operating procedures, the capability of the operator to perform the operation, and the performance of the equipment can be observed.

c. If the full range of gate/valve operation is possible:

(1) Have operation performed using normal power.

(2) Have operation performed using auxiliary power to the extent that maximum power load is demanded.

d. If full gate/valve operation is not possible:

(1) Initially, verify in logbook or other documentation the results of latest full-travel testing by field personnel in accordance with the SOP.

(2) Use normal power to operate gate/valve to the extent possible.

(3) Use auxiliary power to operate gate/valve to the extent possible, at least to a level that demands largest power output by the auxiliary power system (usually during unseating of the gate/valve).

e. If verification of full gate/valve operation cannot be determined by the above procedures, it should be noted in the examination report to test operate the equipment through a full-travel cycle as soon as conditions at the dam permit, but in accordance with these guidelines and the SOP, and to document the accomplished operation and its results in the operating log at the dam.

f. The reasons for an inability to fully operate the equipment during the examination should be documented in the operating log for the facility and in the examination report.

g. The SOP should be reviewed to ensure that adequate procedures exist for periodically testing gates and valves. If the procedures are inadequate, the operating procedures should be updated and/or corrected.

Verification of Full-Travel Operation of Spillway Gates With Continuous High Reservoir Levels

In the particular situation of spillway gates where a continuously high reservoir level exists and, hence, damaging discharges would result from full operation, these guidelines for full-travel operational testing of spillway gates should be considered.

A differential-head (nonfull-travel) test should be performed in accordance with the SOP on each spillway gate (if possible) while subjected to the maximum head expected for the season. If the spillway gates have not been operated in the past year, a 10 percent opening test should be made in progressive steps as follows:

a. Barely raise or crack gate (i.e.; minimum movement that produces flow or additional flow or leakage) - then lower gate.

b. Raise the gate 1 inch - then lower gate.

c. Raise the gate 6 inches - then lower gate.

d. Open the gate 10 percent of total travel - then lower gate. If 10 percent opening is impossible because of downstream restrictions, open it as far as possible - then lower gate.

Full-travel cycling should be performed at scheduled intervals (generally on an annual basis) under a balanced-head (unwatered) condition. However, in the event of a continuously high reservoir, which prohibits a fully open gate for operational testing, tests should be postponed until conditions allow or stoplogs can be installed. Postponement of maximum gate operational testing should not exceed a 6-year period.

In instances where stoplogs are not available for use, full-travel operational testing of spillway gates at scheduled intervals is generally prohibitive due to consequential loss of water or power revenues and the damaging downstream effects from associated large discharges. As a result, such testing may not be accomplished, invariably exceeding the 6-year postponement limitation.

Satisfactory partial-travel gate exercising under differential-head conditions generally ensures hoist reliability for full-travel operation since maximum loading occurs during unseating of the gate. However, if deformation of the spillway structure has occurred, partial-travel exercising does <u>not</u> ensure that the gate can be physically operated through a full-travel cycle without binding. Assurance of full-travel operation can be obtained directly, by performing operational gate testing through the complete cycle (in the dry or against reservoir head), or indirectly, by verifying the alignment and/or designed spacing of the gate guides, wallplates, and structure walls by survey or other means.

Spillway gates which have not been operated full-travel for 6 years or more because of a continuously high reservoir and lack of stoplogs, should be addressed on a case-by-case basis. Estimated costs and impacts resulting from the proposed testing (loss of water and/or power revenues, downstream damages, etc.) need to be evaluated. Following this evaluation, a determination should be made of the necessity of performing actual full-travel testing (with or without stoplogs). If deemed necessary, instructions will need to be provided for such testing. If full-travel testing is not deemed necessary, an indirect means should be provided for checking the capability for full-travel operation of the gates. Indirect testing to verify conformance with design drawings may include surveying the position of gate bay walls, embedded wallplates, and pedestals; measuring clearances between the gate faceplates/guide shoes and bay wall or embedded wallplates; and underwater inspection of wire rope connectors.

In addition to indirect testing, if possible, the coupling on the output shaft of the hoist gear motor should be disconnected and operation of the motor verified.

SPOTLIGHT ON ECHO DAM & RESERVOIR

Weber River Project
Utah

The Weber River Project, formerly designated as the Salt Lake Basin Project, is in the vicinity of Ogden, Utah. It was developed primarily to supply supplemental irrigation water to about 109,000 acres of land east of the Great Salt Lake, lying between the lake and the Wasatch Mountains. Its principal engineering features are Echo Dam and Reservoir, 42 miles southeast of Ogden on the Weber River.

Irrigation of lands from the Weber River started about 1850. The late summer natural flow was sufficient for full water supply for about 3,000 acres; but before many years had passed, a larger area was developed for which there was only a partial supply.

The Bureau of Reclamation (then called Reclamation Service) made a preliminary investigation of this area in 1904 and 1905, which resulted in the Geological Survey establishing stream-gauging stations in 1905. Early in 1922 in cooperation with the Utah State Water Storage Commission, Reclamation started investigations for a storage reservoir. Final selection of a site for the dam and reservoir was made in 1924. Congressional approval and an appropriation for construction of Echo Dam was received in 1924; and the project was approved for construction after 2 years of detailed investigation, design, and legal work.

Construction commenced on November 26, 1927, and was completed in December 1931. It was necessary to relocate portions of the Union Pacific Railroad branch lines and the Lincoln Highway. The original Weber-Provo Diversion Canal also was constructed during this time, and is located about 5 miles north of Kamas, Utah.

Echo Dam is a zoned earthfill structure 1 mile upstream from the town of Echo and about 6 miles north of Coalville in Utah. It has a structural height of 158 feet, crest length of 1,887 feet, and a volume of 1,540,000 yd^3. The spillway has a capacity of 15,000 ft^3/s. The outlet conduit is a concrete-lined horseshoe tunnel to the gatehouse, from which two steel pipes pass through a tunnel to the valvehouse. The outlet works was originally constructed with a capacity of 2,100 ft^3/s. (This capacity has changed to 2,250 ft^3/s based on replacing of the 30-inch needle valves to 30-inch jet-flow gates in April 1987.) For information regarding the replacement of needle valves, refer to Bulletin No. 144, June 1988.

Echo Reservoir has an active capacity of 73,900 acre-feet. Water stored in Echo Reservoir is released as needed by the irrigators. Delivery to the land is made through privately owned distribution systems that divert water from Weber River.

Project soils are deep, fertile, and generally well-drained. They are particularly adapted to production of barley, wheat, corn, alfalfa, potatoes, fruits, vegetables, and sugar beets. An abundance of fruits and vegetables (including tomatoes, peas, beans, cabbage, cherries, peaches, and apricots) are raised primarily for canning purposes. Carload lots of fruits and vegetables are shipped to outside markets.

The project and the recreation facilities at Echo Reservoir are operated and maintained by the Weber River Water Users Association. By agreement, the association also operates and maintains the Weber-Provo Diversion Dam and Canal. The recreation facilities consist primarily of camping, swimming, boating, and water skiing. There were 47,729 visitor-days generated by the facilities during 1977.

Photo 1. - Aerial view of Echo Dam and spillway. 6/13/32

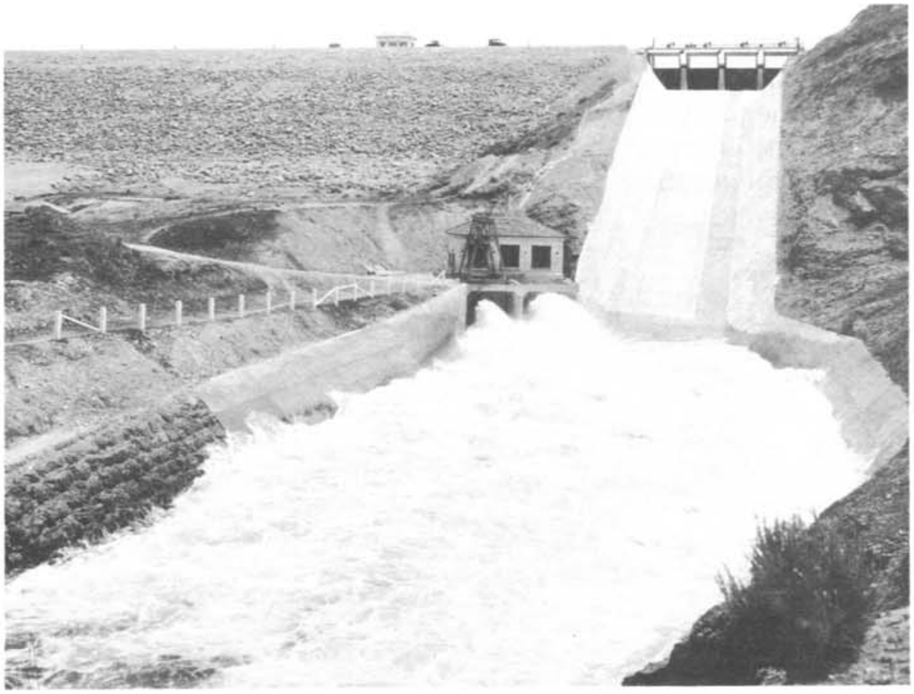
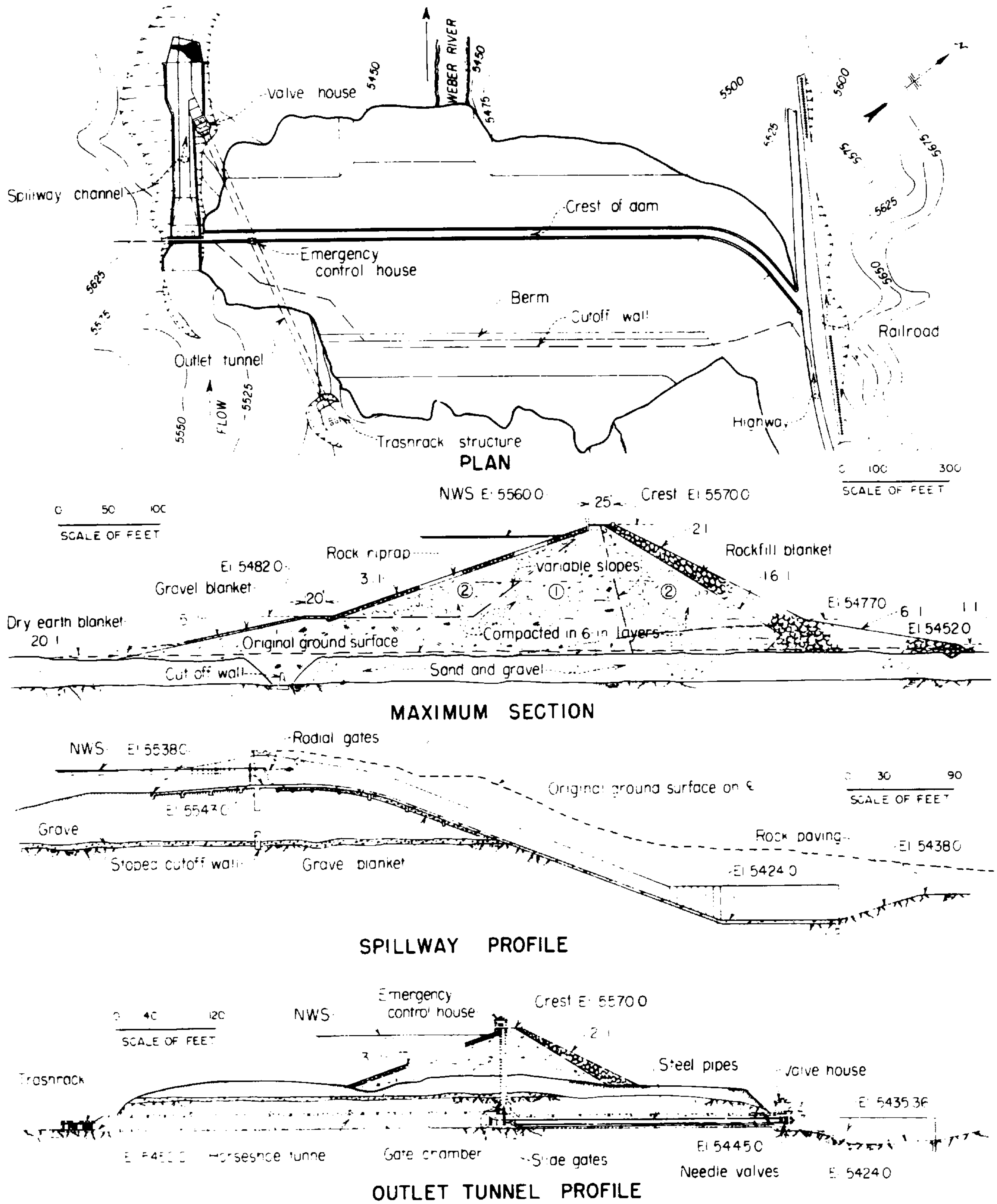
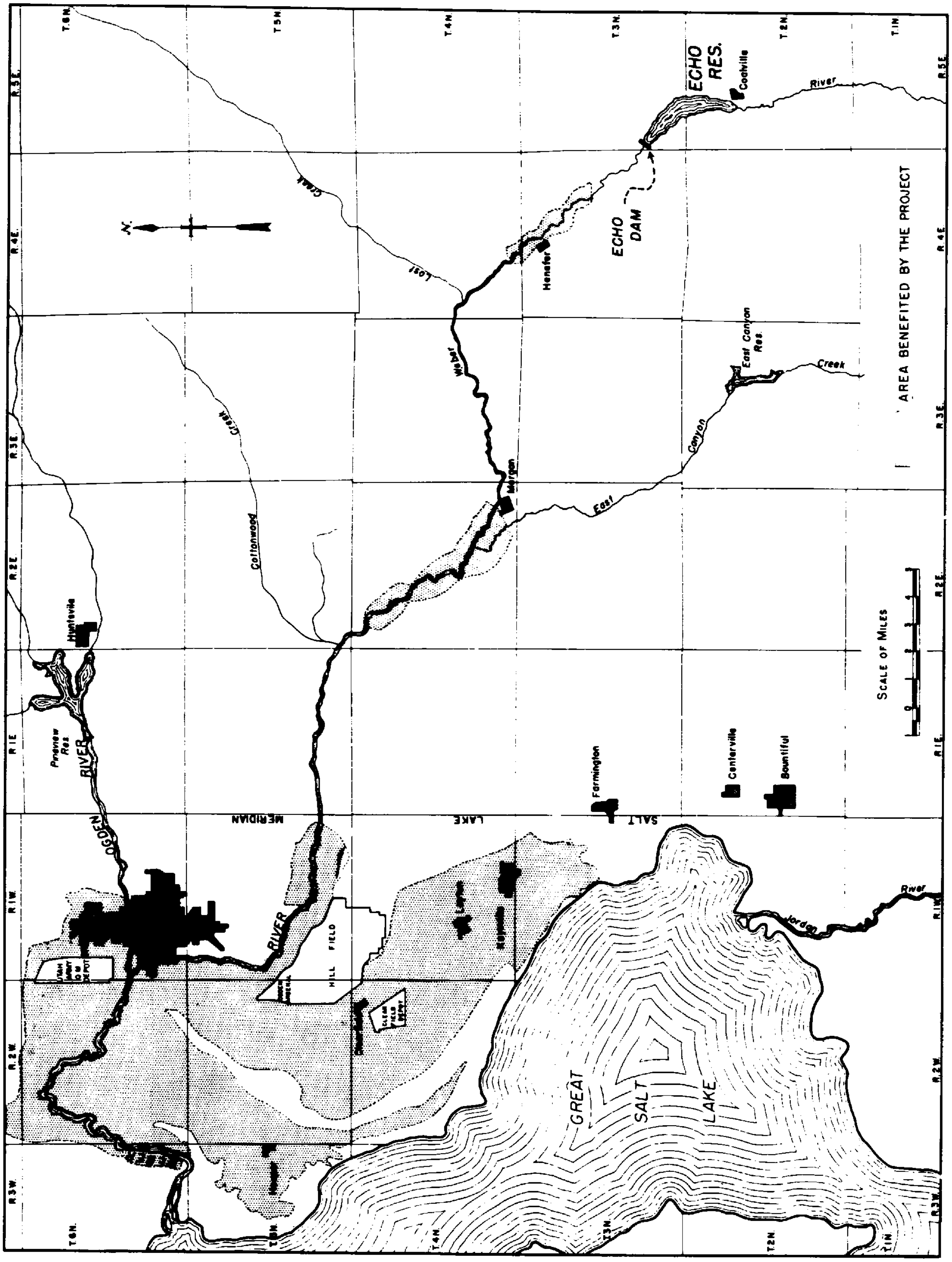


Photo 2. - View of Echo Dam spillway and release from balanced needle valves. 6/13/32 (These needle valves were replaced with jet flow gates in April 1987.)

Photo 3. - Aerial view of Echo Dam and Reservoir. 7/1/58



Echo Dam. Plan and Sections



Weber River Project

CASE STUDY

SAN LUIS DAM - EMBANKMENT UPSTREAM SLOPE FAILURE

Project:	Central Valley
State:	California
Type:	Zoned earthfill
Completed:	1967
Function(s):	Offstream pump storage, irrigation, power
Crest length:	18,600
Hydraulic height:	305 feet
Active capacity:	1,961,000 acre-feet
Surface area:	13,000 acres

Design characteristics: The principal features involved in the construction of San Luis Dam are a zoned earthfill embankment, spillway, outlet works, dike, and roadway.

A cutoff trench of limited width averaging 3 to 5 feet in depth was constructed on the abutments under the dam to reach groutable sedimentary rocks of the Panoche Group of Cretaceous age. These consist of thin- to medium-bedded sandstones, claystones, and clay shales and of medium- to thick-bedded cobble conglomerate. A grout cap was placed into foundation rock in the bottom of the cutoff trench, and a grout curtain was constructed in the foundation. Because of the depth to sedimentary rocks in the valley floor, the cutoff trench was discontinued in the vicinity of San Luis Creek, and upstream and downstream foundation trenches up to 100 feet deep were excavated. These trenches bottom on firm clayey gravel and extend below two weak clay beds in the alluvium. This construction provides for a bond between the impervious core of the dam and the natural impervious blanket, as well as support for the dam between the stability trenches and adjacent to the cutoff. The foundation for the embankment upstream and downstream of the cutoff and foundation trenches was stripped on an average of 2 feet. Fat, saturated, soft clays were found which were considered unstable but were not removed downstream of the cutoff trench.

Zone 1 of the dam, derived from older terrace deposits, is a large central impervious core of the embankment and consists predominantly of clay, clayey gravel, and clayey sand compacted by tamping rollers to 6-inch layers. The zone 2 filter blanket, derived from the San Luis Creek alluvium, consists of mostly selected sand and gravel which had an average of 59 percent plus No. 4 material and was compacted by a crawler-type tractor to 12-inch layers. A miscellaneous zone 3 consisting of sedimentary rock and fat clays was compacted in 12-inch layers. Zones 4 and 5 are rockfill zones derived from basalt quarried from Basalt Hill. Zone 4 is minus 8-inch rock fragments compacted by a crawler-type tractor to 12-inch layers. Zone 5 consisted of plus 8-inch rock. Basalt riprap was placed in 2-foot layers of a 12-inch bedding on the upstream slope below elevation 400. Downstream slope protection was also provided by basalt.

Evidence: Analysis of settlement point survey data and longitudinal cracking observed in 1981 and pre-1981 in the dam crest road gave evidence of embankment settlement prior to the failure. The repeated cracking and patching of the crest road were also evidence of a stability problem prior to the slide.

Incident: After a reservoir drawdown of 180 feet in less than 4 months (May 1 to August 24), an examination team observed a vertical scarp about 2 feet high on the upstream slope of San Luis Dam near the crest that exposed zone 1 embankment. On September 14, 1981, a major slide occurred in the embankment on the upstream left abutment slope. The slide was marked by a prominent head scarp that continued to move and grow both horizontally and vertically after the initial failure. The slide ultimately attained a horizontal length of approximately 1,700 feet and an overall width of 600 feet, extending from dam crest (elevation 554) into the foundation. It involved approximately 1.3 million cubic yards of zones 4 and 5 rockfill, miscellaneous zone 3 fill of sedimentary rock and fat clay, and zone 1 impervious core. Slide movement virtually ceased by mid-December 1981. The slide was obviously critical to the stability of the dam and had to be repaired before filling for the next irrigation season.

Cause: Static analysis indicated a combination of increased pore pressures associated with rapid drawdown of the reservoir and weakening of the natural slope wash (the fat clay which was not excavated from the natural slope during construction), and layers of weakness in the random fill zone 3 material contributed to the failure. The local westward (upstream) and southwestward sloping foundation topography was also associated with the failure.

Remedy: The following plan for investigation and remedial action was prepared and implemented immediately following the incident:

1. Surveys determined the extent of the slide and provided an indicator for progressive slip movement and expansion.

2. An exploration and materials testing program was established to provide information on the mechanism for the slide and to provide reliable data for stability analysis.

3. Inclinometers were installed in six drill holes to locate the depth of the slide. Six additional inclinometers were installed in close proximity to monitor the possible expansion of the slide and slope stability after repairs. The slide proved to be an average of 50 to 60 feet in depth, with a maximum depth of 71 feet.

4. Vibrating-wire piezometers were installed in another six drill holes on the slide to initially monitor pore pressures. Subsequently, piezometers were installed in 11 additional drill holes in the slide area.

5. An evaluation of other areas for potential stability was conducted. It consisted of a battery of tests including index testing, vane shear testing, and other soil testing and analysis. Drill holes equipped with inclinometers and piezometers were completed at other locations on the dam. In addition, existing historical test data were gathered and analyses were performed.

6. The detailed investigations were also reviewed by a panel of consultants for the Bureau of Reclamation and the California Department of Water Resources. It was determined that a 2,100-foot-long stability berm (berm 1) was required along the slide toe to buttress the dam. The berm was constructed with a basal rock drainage blanket (zone 6) and compacted embankment derived by common means from terrace alluvium and weathered sedimentary rocks. It was also determined that the portion of the dam

above the stability berm could be reconstructed to dam crest. In the slide scarp area, a sizable quantity of zones 1, 3, and 4 materials were removed and the embankment reconstructed of rock drainage blanket material covered with plus 8-inch basalt. Berm 1 construction required 1,670,000 yd^3 of material.

7. Additional analysis of existing data and exploration revealed two other upstream areas and one downstream area where foundation conditions required construction of stability berms (foundation topography sloping toward the reservoir or downstream, the presence of slope wash of fat clay, and the absence of the 8:1 sloping embankment buttresses). Upstream berm 2 near the south end of the dam required 420,000 yd^3 and upstream berm 3 north of the intake structure required 714,900 yd^3 of material. Berm 4 on the downstream side near the north end of the dam required 392,160 yd^3. These berms were similar in construction to berm 1 at the slide.

8. Vibrating-wire piezometers and inclinometers were installed in the berms to monitor the behavior of the stability berms. Some of the inclinometer casings contain permanently installed inclinometer instruments for remote readout.

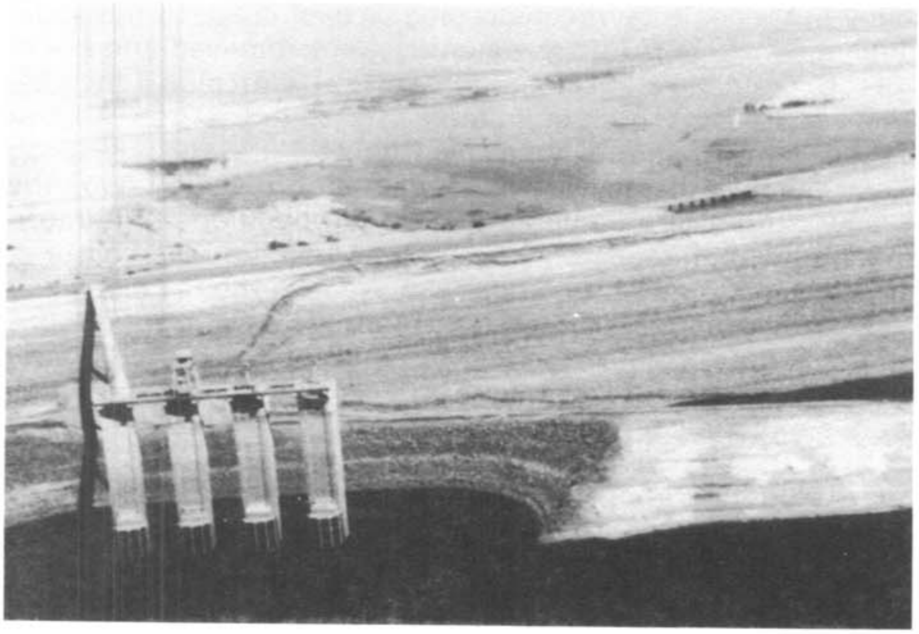
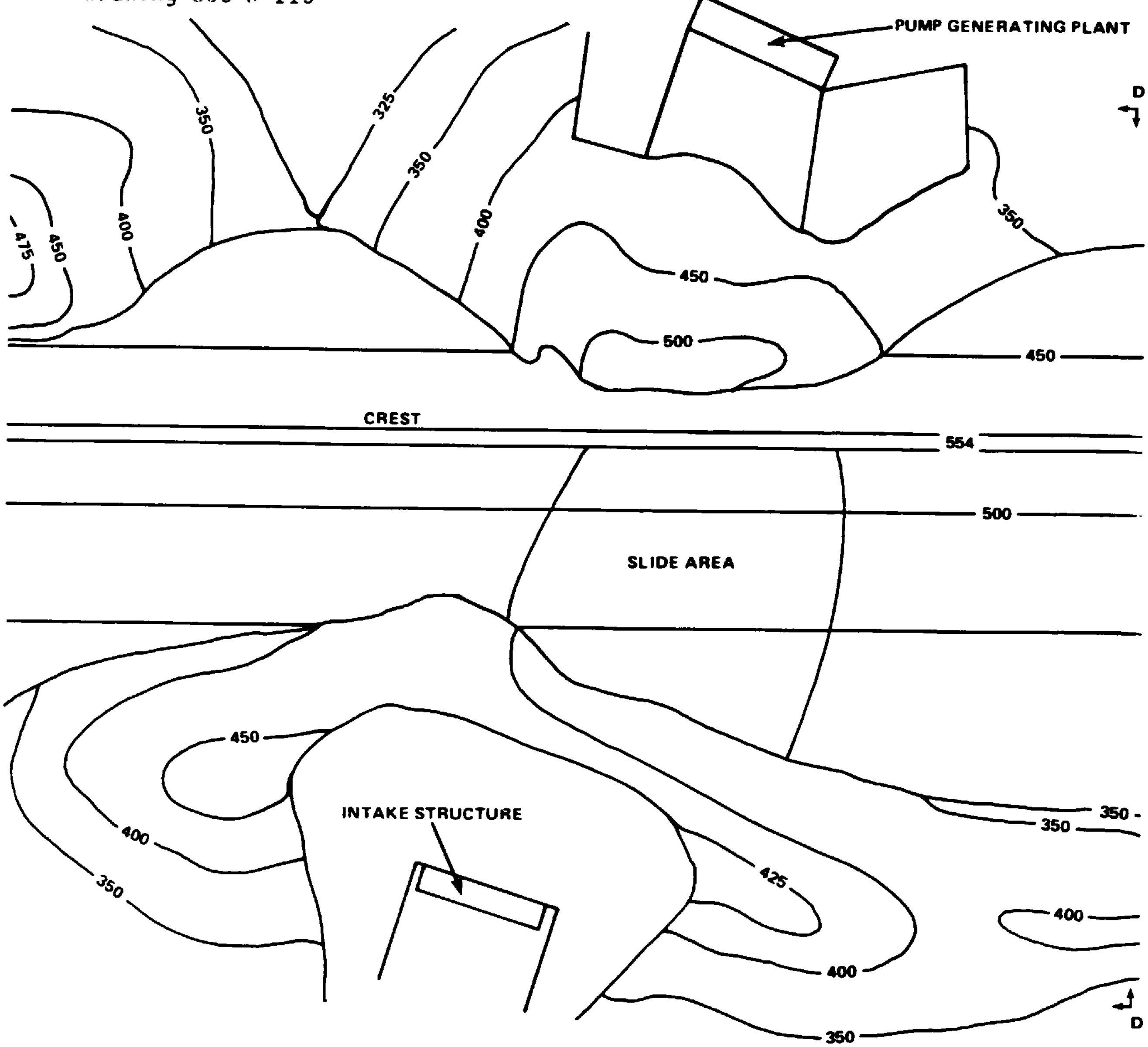


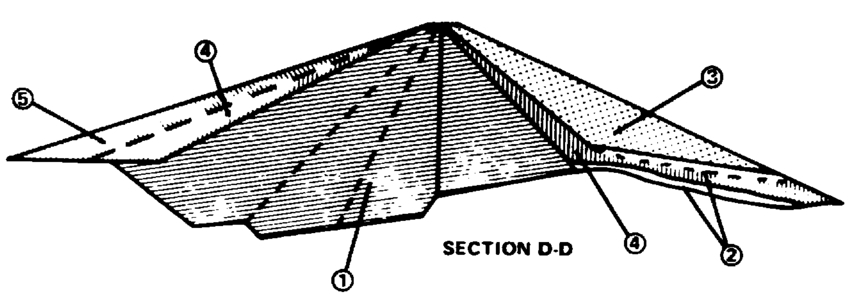
Figure 1. - Showing San Luis Dam failure. 12/81.

Figure 2. - San Luis Dam repair. Aerial view looking easterly at completed berm at upstream station 58, near the right abutment of the dam. 10/82.

drawing 805-D-115



PLAN SECTION AT SLIDE AREA



SECTION D-D

SAN LUIS DAM

WATER SYSTEMS OPERATION AND MAINTENANCE COST INDEX

Trends of operation and maintenance (O&M) costs are known to differ in general from those of construction costs. Therefore, the trends of water systems project O&M costs are not properly measured by existing popular construction cost indices. O&M costs experienced on Bureau of Reclamation irrigation projects have been used to develop an index which measures the trends of these costs.

All Reclamation projects receiving full or supplemental water service for which operation, maintenance, and replacement (OM&R) costs and irrigated acres are reported in the annual Crop Production and Water Utilization Reports are used in computing the Bureau-wide O&M Cost Index. Both Bureau and water user costs are included. This index should be used where there is need to update O&M costs when it is appropriate to do so by use of an index.

O&M cost index numbers for the years 1970 through 1987 are presented in Table 1.

Figure 1 compares graphically the Bureau of Reclamation O&M Cost Index with the Engineering News Record Construction Cost Index and Reclamation's Composite Construction Cost Index. The average O&M cost per irrigated acre for each region also has been calculated and is presented in Table 2. Table 3 provides a breakdown of 1987 cost data by individual district.

Use of O&M Cost Index

The three basic uses of the O&M Cost Index are:

1. To adjust to a common year price level annual O&M costs experienced during a given year.
2. To adjust to the current price level values obtained from O&M cost estimating guides.
3. To adjust to the current price level an O&M cost estimates based on some past price level. This would be appropriate where the earlier estimate is adequately prepared for the proposed use provided the intervening local area wage rate trends are not abnormal. The following example illustrates use of the cost index for adjusting Reclamation's OM&R cost estimates:

   Given: An estimate prepared in 1980 to be adjusted to 1988 costs. Estimates of annual provisions for major replacement and electrical energy costs should be adjusted by using current construction costs and energy rates, respectively.

O&M costs, exclusive of major replacement and energy costs, should be indexed as follows:

Date of Estimate	O&M Cost Index
1980	Use 1979[1] = 113
1988	Use 1987[2] = 205

Ratio of indices $\frac{205}{113} = 1.81$

The 1980 subtotal for personnel, equipment, materials, supplies, administration, and general expenses = \$35,000.

The 1988 subtotal for personnel, equipment, materials, supplies, administration, and general expenses = \$35,000 x 1.81 = \$63,350.

[1] 1979 index is based on same O&M costs experience as used in 1980 O&M estimate.
[2] 1988 O&M estimate would be based on 1987 cost experience, on which the 1987 index is also based.

Table 1.–Water Systems
Operation and Maintenance Cost Index
1977* = 100

Year	Index
1970	66
1971	68
1972	71
1973	74
1974	78
1975	84
1976	92
1977	100
1978	106
1979	113
1980	128
1981	144
1982	153
1983	164
1984	165
1985	181
1986	197
1987	205

* 1976-78 average ($13.32 per irrigated acre)

Table 2.–Average O&M Cost Per Irrigated Acre by Region, 1987

Region	$ Per Acre	Reporting Entities
Pacific Northwest	22.23	108
Mid-Pacific	37.69	118
Lower Colorado	73.64	11
Upper Colorado	9.94	49
Southwest	42.17	15
Missouri Basin	10.42	93
Bureau-wide	27.29	394

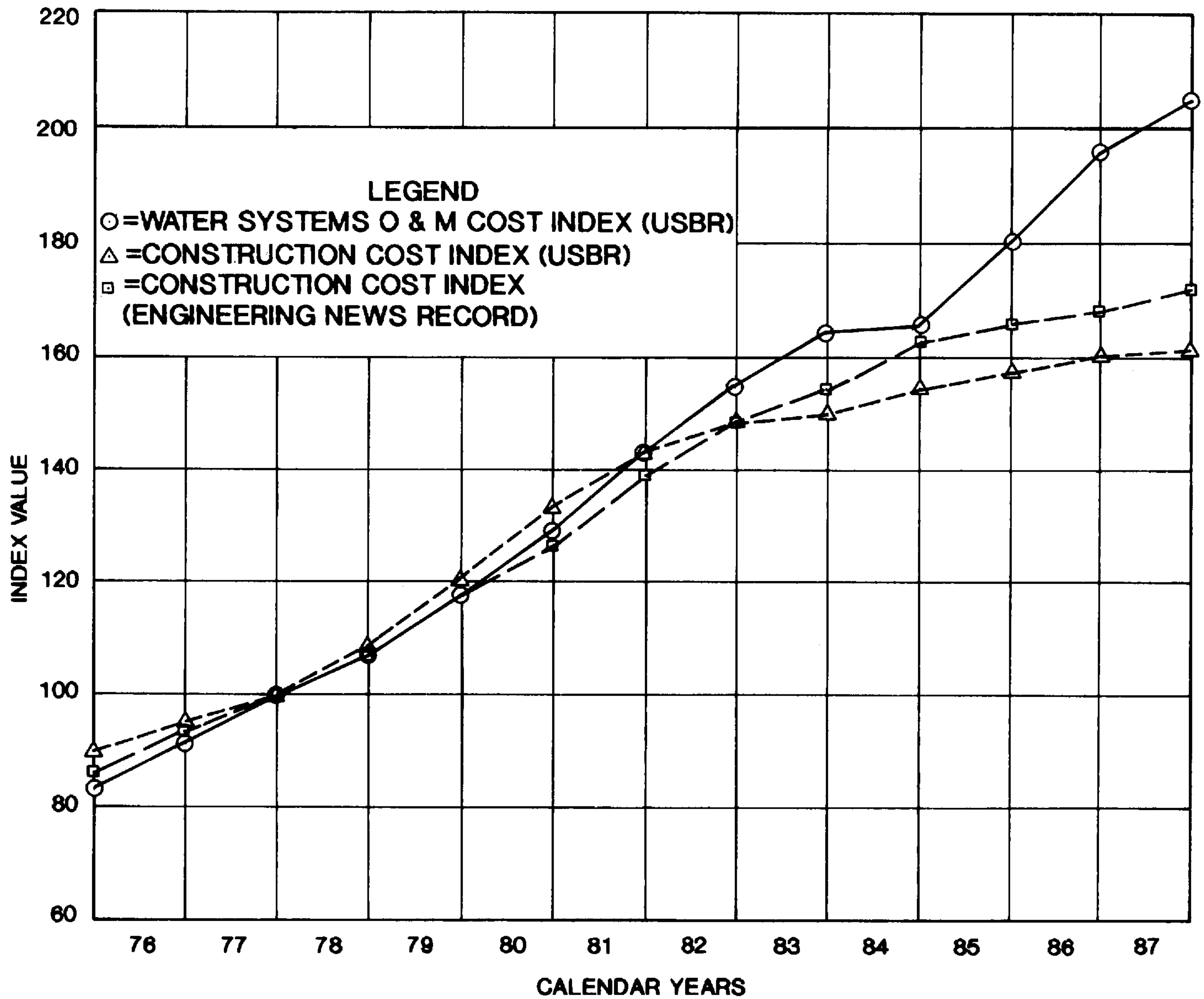


FIGURE 1 - WATER SYSTEMS OPERATION AND MAINTENANCE
COST INDEX COMPARISON
1977=100

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($) BUREAU	WATER USER	TOTAL
PACIFIC NORTHWEST REGION						
ARNOLD	F	1,021	180.02		148.99	148.99
AVONDALE	F	253	137.98		687.43	687.43
BAKER						
LOWER POWDER RIVER I D	S	7,145	208.92		3.40	3.40
BAKER VALLEY I D	S	17,450	170.92		12.97	12.97
BITTER ROOT	F	15,533	134.80		A/ 11.12	A/ 11.12
BOISE, OR-ID						
ARROWROCK DIVISION						
BIG BEND I D	F	1,198	346.02	1.57	29.76	31.33
BOISE-KUNA I D	F	36,357	416.38	1.41	26.67	28.08
NAMPA - MERIDIAN I D	F	25,435	469.56	1.35	25.48	26.83
NEW YORK I D	F	7,882	266.23	1.37	25.75	27.12
SETTLERS I D	F	455	303.53	3.01	22.55	25.56
SP-WN ACT CONTR						
BALLENTYNE D C	S	580	376.13	.10	A/ 9.69	A/ 9.79
BOISE VALLEY IDC	S	1,500	205.82	.11	A/ 6.71	A/ 6.82
CAPITOL VIEW I D	S	318	291.71	.23	A/ 10.33	A/ 10.56
FARMERS CO-OP D C	S	14,555	427.91	.03	A/ 21.99	A/ 22.02
FARMERS UNION D C	S	7,371	319.81	.28	A/ 21.86	A/ 22.14
NAMPA - MERIDIAN I D	S	23,077	416.67	.05	27.96	28.01
NEW DRY CREEK D C	S	2,030	274.42	.11	A/ 11.96	A/ 12.07
PIONEER DITCH C	S	1,220	440.99	.34	A/ 13.99	A/ 14.33
PIONEER I D	S	29,245	461.65	.35	20.22	20.57
RIVERSIDE I D	S	9,111	522.48		A/ 20.01	A/ 20.01
SETTLERS I D	S	8,872	357.65	.06	A/ 21.86	A/ 21.92
SO BOISE MUTUAL I C	S	260	115.69	.34	A/ 18.35	A/ 18.69
WILDER I D	F	44,060	878.46	1.40	26.86	28.26
PAYETTE DIVISION						
BLACK CANYON I D NO 1	F	6,251	845.87		23.39	23.39
BLACK CANYON I D NO 2	F	42,887	408.69	1.38	26.36	27.74
SP-WN ACT CONTR						
EMMETT I D	S	20,180	467.43	3.93	9.76	13.69
FARMERS CO-OP I C	S	15,035	428.86	.15	A/ 14.73	A/ 14.88
LOWER PAYETTE D C	S	11,844	407.12	.05	A/ 13.78	A/ 13.83
BURNT RIVER	S	15,070	175.40		1.95	1.95
CHIEF JOSEPH DAM						
CHELAN DIVISION						
LAKE CHELAN RECL DIST	F	5,946	3,310.02	62.96	57.59	120.55
FOSTER CREEK DIVISION						
BREWSTER FLAT I D	F	2,316	2,350.81		55.55	55.55
BRIDGEPORT BAR I D	F	425	1,838.31		26.37	26.37
GREATER WENATCHEE DIVISION	F	6,196	6,030.79		86.93	86.93
OKANOGAN-SIMILKAMEEN						
OROVILLE-TONASKET I D	F	7,819	2,477.05		97.67	97.67
WHITESTONE COULEE UNIT	S	2,615	1,147.64		35.03	35.03
COLUMBIA BASIN						
EAST COLUMBIA BASIN I D	F	111,171	520.18	5.05	29.40	34.45
QUINCY-COLUMBIA BASIN I D	F	206,499	644.79	4.50	24.92	29.42
SOUTH COLUMBIA BASIN I D	F	187,946	699.52	3.37	24.70	28.07
CRESCENT LAKE DAM	F	9,076	220.53		34.01	34.01
CROOKED RIVER	F	15,707	379.89		18.45	18.45
DALTON GARDENS	F	9	40.00		117.78	117.78
DESCHUTES						
1/ CENTRAL OREGON I D	S	43,730	193.50		24.61	24.61
CROOK COUNTY IMP D NO 1	S	2,285	334.47	-	A/ 19.08	A/ 19.08
NORTH UNIT I D	F	41,046	601.33		27.97	27.97
FRENCHTOWN	F	3,835	204.06		8.11	8.11
1/ KING HILL I D	F	7,684	615.34		114.41	114.41
LITTLE WOOD RIVER	S	4,489	121.61		2.36	2.36
MANN CREEK						
MANN CREEK I D	S	3,376	311.35		3.13	3.13
MONROE CREEK I D	S	830	217.86		12.56	12.56
MICHAUD FLATS	F	9,668	507.50	.85	38.18	39.03
MINIDOKA-PALISADES						
A-B IRRIGATION DISTRICT	F	67,935	590.19	.25	38.50	38.75
AMERICAN FALLS RES D NO 2	B	76,506	429.51	1.83	28.34	30.17
BURLEY I D	F	39,511	569.43	1.84	29.79	31.63
FREMONT-MADISON I D	S	99,400	260.18	.53	A/ 1.43	A/ 1.96
MINIDOKA I D	F	59,067	556.18	.99	17.44	18.43
SP-WARREN ACT CONTR						
ABOVE AMERICAN FALLS	S	323,716	300.01	.55	A/ 6.94	A/ 7.49
BELOW AMERICAN FALLS	S	356,762	437.54	.53	A/ 6.64	A/ 7.17
MISSOULA VALLEY	F	150	170.50		A/ 19.79	A/ 19.79
OKANOGAN	F	4,197	1,291.92		71.81	71.81
OWYHEE, OR-ID						
NORTH DIVISION						
ADVANCEMENT I D	F	239	596.08		20.33	20.33
BENCH I D	F	2,125	924.46		22.19	22.19
CRYSTAL I D	F	984	960.11		26.45	26.45
ONTARIO-NYSSA I D	F	5,294	5,007.61		22.40	22.40
OWYHEE IRRIGATION DIST	F	42,583	669.08		23.76	23.76
PAYETTE-OREGON SLOPE I D	F	4,298	1,257.95		22.14	22.14
SLIDE IRRIGATION DIST	F	1,097	1,021.28		21.21	21.21
OWYHEE DITCH COMPANY	S	12,475	1,036.09		A/ 21.24	A/ 21.24
SOUTH DIVISION						
GEM I D	F	29,080	457.92		28.26	28.26

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($) BUREAU	WATER USER	TOTAL
RIDGEVIEW I D	F	5,717	427.34		25.11	25.11
RATHDRUM PRAIRIE						
EAST GREENACRES I D	F	4,080	167.57		40.92	40.92
HAYDEN LAKE I D	F	1,092	152.41		A/ 63.79	A/ 63.79
POST FALLS I D	F	1,753	210.77		51.59	51.59
ROGUE RIVER BASIN						
TALENT DIVISION						
MEDFORD I D	F	6,745	1,161.06	.59	41.70	42.29
ROGUE RIVER VALLEY I D	S	6,098	441.73	1.65	28.69	30.34
TALENT I D	S	12,088	704.52	3.71	37.52	41.23
1/ SALMON RIVER CANAL C	S	21,948	246.59		A/ 12.90	A/ 12.90
SPOKANE VALLEY	F	4,240	283.97		112.33	112.33
THE DALLES	F	5,414	2,313.65		38.89	38.89
TUALATIN	F	13,516	2,086.89	1.41	28.17	29.58
UMATILLA						
EAST DIVISION						
HERMISTON I D	F	7,800	228.77		26.89	26.89
SOUTH DIVISION						
STANFIELD I D	S	5,477	409.83	1.91	44.53	46.44
WESTLAND I D	S	6,293	238.24	1.95	A/ 45.48	A/ 47.43
WEST DIVISION						
WEST EXTENSION I D	F	5,500	194.73		45.94	45.94
VALE	F	32,707	247.59		17.13	17.13
WAPINITIA	S	2,018	242.30		A/ 14.08	A/ 14.08
1/ WENATCHEE HEIGHTS RECL D	F	739	1,148.39		83.48	83.48
YAKIMA						
KENNEWICK DIVISION	F	8,764	907.93	8.65	96.72	105.37
KITTITAS DIVISION	F	52,065	350.66	2.71	12.84	15.55
ROZA DIVISION	F	65,599	1,483.99	3.51	46.49	50.00
SUNNYSIDE DIVISION						
BENTON I D	F	2,846	908.17	.94	56.50	57.44
GRANDVIEW I D	F	2,901	1,233.45	1.00	57.35	58.35
GRANGER I D	F	1,231	804.45	.95	69.60	70.55
OUTLOOK I D	F	3,603	875.15	.94	A/ 50.90	A/ 51.84
PROSSER I D	F	1,531	1,016.18	1.03	61.64	62.67
SNIPES MOUNTAIN I D	F	1,157	841.34	.96	40.53	41.49
SUNNYSIDE VALLEY I D	F	58,875	1,045.45	.93	33.18	34.11
SP-WN ACT CONTR						
BROADWAY I D	S	14	5,000.00	6.79	19.79	26.58
CASCADE I D	S	10,671	199.73	.49	25.47	25.96
MOXEE	S	325	2,062.63	.51	74.44	74.95
NACHES-SELAH I D	S	9,300	1,454.27	.51	41.51	42.02
SELAH-MOXEE I D	S	6,165	1,410.32	.49	A/ 54.50	A/ 54.99
SMALL WARREN ACT CONTR	S	80	365.00	.54		.54
TERRACE HEIGHTS I D	S	270	819.85	.76	A/ 34.55	A/ 35.31
UNION GAP I D	S	3,100	1,978.46	.54	37.63	38.17
WEST SIDE I C	S	5,800	246.38	.58	10.47	11.05
YAKIMA VALLEY C C	S	2,430	1,448.29	.51	29.11	29.62
TIETON DIVISION						
YAKIMA-TIETON I D	F	25,574	1,447.02	2.01	A/ 4.50	A/ 6.51
MID-PACIFIC REGION						
1/ BROWNS VALLEY I D	S	7,559	253.98		10.66	10.66
1/ BYRON-BETHANY I D	S	9,835	847.08		75.75	75.75
CACHUMA						
CARPINTERIA CY W D	S	3,442	15,889.78		189.05	189.05
2/ GOLETA CY W D	S	6,842	3,811.37		103.54	103.54
SUMMERLAND CY W D	S	153	2,388.00		364.64	364.64
1/ CAMROSA COUNTY W D	S	3,620	5,962.76		485.15	485.15
CENTRAL VALLEY						
AMERICAN RIVER DIV						
FOLSOM UNIT						
SAN JUAN SUBURBAN W D	S	2,054	1,156.10	.44		.44
SLY PARK UNIT						
EL DORADO I D	S	5,659	1,527.34	1.28	191.46	192.74
DELTA DIVISION						
CONTRA COSTA CANAL						
CONTRA COSTA W D	S	1,170	491.99	.44	111.79	112.23
DELTA-MENDOTA						
2/ BANTA-CARBONA I D	S	15,464	1,047.37	12.47	71.26	83.73
3/ BROADVIEW W D	S	7,870	900.64	22.10	134.78	156.88
CENTINELLA W D	F	425	1,829.18	39.33	5.23	44.56
DAVIS WATER DISTRICT	F	1,393	1,692.21	31.54	3.23	34.77
DEL PUERTO W D	F	3,505	1,593.58	28.72	2.82	31.54
EAGLE FIELD W D	S	1,306	835.65	22.59		22.59
FOOTHILL WATER DIST	F	3,190	1,507.29	27.68	2.78	30.46
FRESNO SLOUGH W D	S	910	858.44	34.28		34.28
HOSPITAL W D	F	9,436	1,734.73	30.36	2.79	33.15
HUGHES, MELVIN D	S	35	660.34	2.86		2.86
JAMES IRRIGATION DIST	S	21,635	823.36	17.09	42.34	59.43
KERN CANON W D	F	2,320	1,483.46	27.60	1.72	29.32
MERCY SPRINGS W D	F	2,336	271.93	56.58	23.25	79.83
MUSTANG WATER DIST	F	3,672	791.55	34.53	2.96	37.49
ORESTIMBA W D	F	5,052	1,337.28	24.37	2.56	26.93
ORO LOMA W D	S	992	339.20	36.26		36.26
PACHECO W D	S	1,936	1,393.21	30.43		30.43
PANOCHE W D	S	22,166	824.43	15.31	51.41	66.72

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

	REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($) BUREAU	WATER USER	TOTAL
	PATTERSON W D	S	6,625	1,745.56	18.85	100.45	119.30
	PLAIN VIEW W D	F	5,050	1,076.04	34.87	21.78	56.65
	QUINTO W D	S	1,985	1,174.98	33.95	3.65	37.60
	RECLAMATION D #1606	S	117	820.80	14.74		14.74
	ROMERO W D	S	915	1,210.10	46.00	4.70	50.70
	SALADO W D	F	2,916	1,194.67	21.68	3.24	24.92
	SAN LUIS W D	S	9,016	1,388.36	28.36	180.21	208.57
	SUNFLOWER W D	F	4,027	1,007.37	36.56	3.04	39.60
	THE WEST SIDE I D	S	8,280	688.69	6.50	63.27	69.77
	TRACTION RANCH-CASPER	S	2,014	582.53	17.37		17.37
	TRANQUILLITY I D	S	8,669	696.69	12.79	59.71	72.50
	WEST STANISLAUS I D	S	20,755	2,317.38	20.57		20.57
	WIDREN W D	S	765	776.69	33.56		33.56
	FRIANT DIV						
	FRIANT-KERN CANAL						
1/	ALPAUGH I D	S	5,000	626.03		133.10	133.10
3/	ARVIN-EDISON WSD	S	97,135	2,473.07	4.78	66.32	71.10
	DELANO-EARLIMART I D	S	49,455	1,988.55	15.60	24.52	40.12
	EXETER I D	S	10,874	11,052.09	7.31	33.42	40.73
	FRESNO I D	S	166,083	2,325.47	.92	26.56	27.48
3/	GARFIELD W D	S	1,523	4,134.65	17.56		17.56
	GREEN VALLEY W D	S	552	816.20	4.99		4.99
	HILLS VALLEY I D	S	1,987	2,891.46	14.17	76.03	90.20
	INTERNATIONAL W D	S	480	5,374.28	15.43	75.78	91.21
	IVANHOE I D	S	9,772	2,718.48	5.03	31.27	36.30
	KERN-TULARE W D	S	15,262	2,962.09	25.39		25.39
3/	LEWIS CREEK W D	S	1,075	2,239.16	8.73		8.73
	LINDMORE I D	S	23,957	3,114.31	8.02		8.02
	LINDSAY-STRATHMORE I D	S	12,643	4,070.90	14.94		14.94
	LOWER TULE RIVER I D	S	74,558	1,123.69	13.59	10.37	23.96
	ORANGE COVE I D	S	23,415	3,051.46	9.32		9.32
	PIXLEY W D	S	49,943	962.06	6.16		6.16
	PORTERVILLE I D	S	13,367	1,449.96	9.77		9.77
	RAG GULCH W D	S	5,739	1,718.22	18.43		18.43
3/	SAUCELITO I D	S	15,555	1,767.25	9.91		9.91
	SHAFTER-WASCO I D	S	30,887	2,711.91	12.60	22.12	34.72
	SO SAN JOAQUIN MUD	S	46,136	1,746.11	13.91		13.91
	STONE CORRAL I D	S	5,404	3,181.43	8.84	45.41	54.25
	TEA POT DOME W D	S	3,081	3,371.63	12.96	111.03	123.99
3/	TERRA BELLA I D	S	11,315	4,098.00	14.05	183.21	197.26
	TRI-VALLEY W D	S	564	2,090.77	20.25		20.25
	TULARE I D	S	60,881	997.14	3.17	2.56	5.73
	MADERA CANAL						
3/	CHOWCHILLA W D	S	47,985	1,094.50	11.63	22.69	34.32
	MADERA I D	S	94,971	1,556.91	7.90	21.97	29.87
	SACRAMENTO RIVER DIV						
	CORNING CANAL						
	CORNING W D	S	5,011	363.18	39.76		39.76
	ELDER CREEK W D	F	1,068	304.87	26.05		26.05
3/	PROBERTA W D	F	1,970	256.71	17.18		17.18
	THOMES CREEK W D	S	1,727	401.19	30.21	1.12	31.33
	TEHAMA-COLUSA						
	COLUSA COUNTY W D	S	28,678	1,037.39	14.36	8.08	22.44
	CORTINA W D	F	478	222.95	23.87		23.87
	DAVIS W D	S	890	899.57	30.81		30.81
	DUNNIGAN W D	S	5,793	551.17	15.55		15.55
	FOUR-M W D	F	868	507.33	18.69		18.69
	GLENN VALLEY W D	F	379	769.33	12.75		12.75
	GLIDE WATER DIST	F	3,443	480.51	19.92		19.92
	HOLTHOUSE W D	F	478	685.54	30.58		30.58
3/	KANAWHA W D	F	11,093	396.70	21.97	18.38	40.35
	KIRKWOOD W D	F	153	290.27	20.53		20.53
	LA GRANDE W D	F	1,109	480.89	34.77		34.77
	MYERS-MARSH MWC	S	225	288.91	11.12		11.12
	ORLAND-ARTOIS W D	S	20,182	579.69	22.23	31.88	54.11
	RICHFIELD W D	S	60	248.70	16.10		16.10
	TEHAMA W D	F	122	300.00	6.09		6.09
3/	WESTSIDE W D	S	9,409	732.64	25.89		25.89
	SHASTA DIVISION						
	SHASTA DAM UNIT						
	ANDERSON-COTTONWOOD ID	S	19,194	243.37	.97	22.09	23.06
	COLUSA I C	S	197	637.69	.94		.94
3/	FEATHER W D	S	7,072	1,357.44	4.54		4.54
2/	GLENN-COLUSA I D	S	96,600	492.68	1.95	38.93	40.88
	MAXWELL I D	S	3,380	388.03	1.65		1.65
	MERIDIAN FARMS W C	S	7,579	549.49	3.11		3.11
	MISCELLANEOUS CONTR	S	52,341	642.30	1.26		1.26
	NATOMAS CENTRAL MWD	S	21,016	468.99	1.95		1.95
	PELGER MUTUAL W C	S	2,073	604.26	1.30		1.30
	PLEASANT GROVE-VERONA	S	4,640	571.71	1.00		1.00
	PRINCETON-CODORA-GLENN	S	6,871	517.17	4.06		4.06
	PROVIDENT I D	S	10,203	427.73	.91	29.49	30.40
	RECL DIST NO 1004	S	10,320	443.94	2.70		2.70
	ROBERTS DITCH I C	S	1,330	576.74	.42		.42
	SARTAIN MUTUAL W C	S	636	496.76	2.18		2.18
	SUTTER MUTUAL W C	S	33,218	859.23	5.19		5.19
	SWINFORD TRACT I C	S	184	1,549.40	.57		.57

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($) BUREAU	WATER USER	TOTAL
TISDALE I&D C	S	1,876	504.75	1.98		1.98
TRINITY RIVER DIV						
CLEAR CREEK SOUTH UNIT						
CLEAR CREEK CSD	F	3,121	381.56	11.40		11.40
COW CREEK UNIT						
BELLA VISTA W D	S	1,548	170.36	34.72	195.20	229.92
W SAN JOAQUIN DIV						
SAN LUIS CANAL						
PACHECO W D	S	1,562	1,413.37	23.30		23.30
PANOCHE W D	S	12,078	749.69	41.51		41.51
3/ SAN LUIS W D	S	28,888	1,576.96	33.27		33.27
WESTLANDS W D	S	500,598	1,497.17	23.88	21.89	45.77
COE PROJ(INTGR)						
BUCHANAN UNIT						
COE PROJ(NON-INTGR)						
NEW HOGAN						
1/ GEORGETOWN DIVIDE PUD	S	1,869	762.64		157.30	157.30
HUMBOLDT	S	32,800	389.55		11.36	11.36
KLAMATH, OR-CA						
2/ SAN BENITO	S	22,445	1,824.92	1.28		1.28
SOLANO						
1/ SOUTH SUTTER W D	S	26,429	516.43		15.75	15.75
1/ TEHACHAPI-CUMMINGS CY W D	S	1,903	7,517.38		99.20	99.20
LOWER COLORADO REGION						
BOULDER CANYON, CA-AZ-NV						
ALL-AMERICAN CANAL						
COACHELLA DIVISION	F	59,829	4,489.12		59.06	59.06
IMPERIAL DIVISION	F	455,718	1,164.76		49.01	49.01
GILA						
WELLTON-MOHAWK DIVISION	F	59,331	1,455.29		68.26	68.26
YUMA MESA DIVISION						
MESA UNIT	F	16,949	1,045.51		50.10	50.10
NORTH GILA VALLEY UNIT	F	6,128	5,249.68		17.68	17.68
SOUTH GILA VALLEY UNIT	F	9,655	4,903.57		34.65	34.65
SALT RIVER						
SALT RIVER VALLEY WUA	F	51,319	1,430.41		338.72	338.72
YUMA, CA-AZ						
RESERVATION DIV						
BARD UNIT	F	6,522	4,484.40		42.62	42.62
INDIAN UNIT	F	5,106	1,958.58		46.81	46.81
VALLEY DIVISION, AZ	F	45,921	3,050.78		76.93	76.93
YUMA AUXILIARY	F	2,649	1,465.30		118.41	118.41
UPPER COLORADO REGION						
BOSTWICK PARK	S	4,854	120.03		11.10	11.10
CENTRAL UTAH						
BONNEVILLE UNIT						
DUCHESNE RIVER	S	15,197	161.50		2.17	2.17
JENSEN UNIT	S	3,880	244.25		2.46	2.46
VERNAL UNIT	S	13,013	170.07		3.68	3.68
COLLBRAN	S	20,210	105.38	1.19	2.68	3.87
EDEN	F	15,989	107.56		7.07	7.07
EMERY COUNTY						
COTTONWOOD CREEK CONS I C	S	4,807	180.44		7.42	7.42
HUNTINGTON-CLEVELAND I C	S	12,616	101.26		11.30	11.30
FLORIDA	S	14,765	141.32		6.04	6.04
2/ FRUITGROWERS DAM	S	2,295	317.41		10.24	10.24
GRAND VALLEY						
GARFIELD GRAVITY DIV	F	19,601	293.19		24.59	24.59
ORCHARD MESA DIVISION	F	5,568	1,396.44		73.06	73.06
HAMMOND	F	3,492	286.19		27.48	27.48
HYRUM	S	6,394	253.34		5.21	5.21
LYMAN	S	37,064	64.04		.86	.86
1/ MALAD VALLEY I C	S	5,600	128.97		5.34	5.34
MANCOS	S	7,114	124.77		10.51	10.51
MIDVIEW EXCHANGE	S	6,027	105.83		9.04	9.04
MOON LAKE WUA	S	72,676	109.12		1.30	1.30
NAVAJO UNIT, CRSP	F	230	6.52		12.00	12.00
NEWTON	S	2,591	396.05		6.12	6.12
OGDEN RIVER						
1/ WEBER-BOX ELDER C D, PROJ1	S	365	875.64		18.18	18.18
1/ WEBER-BOX ELDER C D, PROJ2	S	825	731.77		27.15	27.15
OTHER PROJECT LANDS	S	13,373	820.62		3.54	3.54
PAONIA	S	10,639	152.03		7.58	7.58
PINE RIVER						
PINE RIVER, CO	S	32,162	131.89		6.71	6.71
PRESTON BENCH	S	5,191	243.09		5.23	5.23
PROVO RIVER	S	36,249	357.90		6.27	6.27
SANPETE						
EPHRAIM DIVISION	S	6,730	122.45		2.87	2.87
SPRING CITY DIVISION	S	6,830	199.04		1.78	1.78
SCOFIELD	S	15,305	221.26		.64	.64
1/ SETTLEMENT CANYON I C	S	835	338.28		54.00	54.00

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($)		
				BUREAU	WATER USER	TOTAL
SILT	S	5,143	166.93		17.41	17.41
SMITH FORK	S	8,924	119.43		9.58	9.58
STRAWBERRY VALLEY						
HIGHLINE DIVISION	F	15,685	359.85		16.21	16.21
SPANISH FORK DIVISION	S	16,832	273.86		9.86	9.86
SPRINGVILLE-MAPLETON DIV	S	7,925	288.75		3.77	3.77
UNCOMPAHGRE						
UNCOMPAHGRE CLASS 1-3	F	58,874	300.89		24.68	24.68
WEBER BASIN						
1/ BOUNTIFUL WATER SUBCON D	S	456	1,198.72		76.17	76.17
1/ CENTERVILLE-DEUEL CRK I D	S	396	7,756.10		123.33	123.33
1/ FARMINGTON AREA PRESS. I D	S	2,338	350.24		24.70	24.70
1/ HAIGHTS CREEK I C	S	1,805	342.63		49.00	49.00
1/ KAYS CREEK I C	S	324	431.42		38.94	38.94
1/ SOUTH DAVIS CY WID	S	246	1,676.96		350.12	350.12
OTHER PROJECT LANDS	S	20,870	936.00		13.39	13.39
WEBER RIVER						
1/ HOOPER IRRIGATION COMPANY	S	10,471	324.92		19.38	19.38
1/ ROY WATER CONSERV SUBD	S	840	827.65		280.59	280.59
1/ SOUTH WEBER WID	S	537	236.06		57.73	57.73
OTHER PROJECT LANDS	S	80,040	419.29		6.10	6.10
SOUTHWEST REGION						
1/ BROWNSVILLE IDD	F	10,394	511.94		44.72	44.72
CARLSBAD	F	22,745	330.53		30.84	30.84
1/ DONNA I D	F	28,572	587.24		31.11	31.11
FORT SUMNER	F	5,835	144.38		23.19	23.19
1/ HARLINGEN I D	F	32,341	372.76		16.61	16.61
LOWER RIO GRANDE REHAB						
LA FERIA DIVISION	F	27,500	629.20		11.12	11.12
MERCEDES DIVISION	F	54,387	662.21		20.13	20.13
MIDDLE RIO GRANDE	F	56,127	357.35	4.60	98.72	103.32
RIO GRANDE						
RIO GRANDE, NM						
ELEPHANT BUTTE I D	F	77,597	1,354.91	3.81	39.98	43.79
RIO GRANDE, TX						
EL PASO CY WID NO 1	F	47,428	812.39	3.23	41.60	44.83
HUDSPETH CY NO 1	S	15,043	667.07		41.82	41.82
SAN JUAN-CHAMA	F	2,162	221.58	162.72	55.41	218.13
1/ SANTA MARIA I D	F	3,791	361.37		20.69	20.69
TUCUMCARI	F	26,134	141.30		28.67	28.67
VERMEJO	F	5,238	102.37		25.53	25.53
WASHITA BASIN						
MISSOURI BASIN REGION						
BUFFALO RAPIDS						
2/ IRRIGATION DISTRICT NO 1	F	11,679	312.87		19.87	19.87
2/ IRRIGATION DISTRICT NO 2	F	8,603	234.57		19.21	19.21
BUFORD-TRENTON	F	8,041	474.46		19.13	19.13
2/ CENTRAL NEBRASKA PP&ID	S	116,522	238.98	.05	15.09	15.14
COLORADO-BIG THOMPSON	S	629,631	348.45	.78	1.95	2.73
1/ COONEY DAM REHAB	S	17,750	273.09	.39		.39
1/ FORT COLLINS, CITY OF	S	1,594	206.58		1.42	1.42
FRYINGPAN-ARKANSAS	S	166,996	246.61	1.08		1.08
HUNTLEY	F	25,365	255.30		24.33	24.33
INTAKE	F	769	104.37		2.71	2.71
KENDRICK	F	21,674	88.23	.46	11.07	11.53
LOWER YELLOWSTONE						
DISTRICT NO 1, MT	F	27,535	355.62		24.60	24.60
DISTRICT NO 2, ND	F	16,217	485.92		19.61	19.61
MILK RIVER						
CHINOOK DIVISION	F	34,607	73.63	.91	6.94	7.85
DODSON PUMPING UNIT	F	922	48.43	1.10	6.77	7.87
FORT BELKNAP INDIAN RESV	F	4,136	41.16	1.85	34.87	36.72
GLASGOW DIVISION	F	10,718	82.09	1.85	24.51	26.36
MALTA DIVISION	F	38,914	48.94	.66	10.78	11.44
PRIVATE PUMPERS PERMANENT	F	9,514	74.83	1.85	.97	2.82
MIRAGE FLATS	F	9,102	284.07		12.43	12.43
NORTH PLATTE						
NEBRASKA LANDS						
GERING-FT LARAMIE I D	F	51,147	296.12	3.23	15.68	18.91
NORTHPORT I D	F	15,659	223.99	1.47	9.48	10.95
PATHFINDER I D	F	86,313	222.43	1.70	16.18	17.88
SP-WARREN ACT CONTR						
BEERLINE ICC	S	880	89.14	.74	18.24	18.98
BROWNS CREEK I D	S	5,589	134.56	1.46	7.12	8.58
CENTRAL I D	S	1,557	260.47	1.04	11.86	12.90
CHIMNEY ROCK I D	S	5,306	165.42	.82	6.74	7.56
FARMERS I D	S	60,564	216.50	.64	17.69	18.33
GERING I D	S	11,562	228.15	1.13	10.09	11.22
WYOMING LANDS						
GOSHEN I D	F	49,867	259.39	1.50	4.41	5.91
SP-WARREN ACT CONTR						
HILL I D	S	3,336	217.22	1.21	11.50	12.71
LINGLE WUA	S	10,710	218.68	1.36	6.59	7.95
ROCK RANCH D C	S	900	387.52	1.42	2.22	3.64
WYOMING NON-DIST LANDS	F	1,603	246.72	1.07	7.39	8.46

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($) BUREAU	WATER USER	TOTAL
1/ NORTH POUDRE I C	S	31,752	213.37		7.97	7.97
PICK-SLOAN MBP						
BELLE FOURCHE UNIT	F	52,327	165.99	.06	8.70	8.76
BIGHORN BASIN DIV						
HANOVER-BLUFF UNIT						
HIGHLAND-HANOVER I D	F	5,451	403.27	1.55	17.23	18.78
UPPER BLUFF I D	F	1,333	424.10	1.49	15.49	16.98
OWL CREEK UNIT						
LUCERNE PUMP	S	3,480	144.98	.06	4.00	4.06
MIDDLE & UPPER	S	8,470	96.63	.06	5.00	5.06
BOSTWICK DIV						
KANSAS-BOSTWICK I D	F	33,585	209.36	1.48	17.69	19.17
NEBRASKA-BOSTWICK I D	F	18,415	248.78	1.39	18.42	19.81
BOYSEN DIVISION						
BOYSEN UNIT						
HANOVER I D	S	8,250	411.82	.02	12.61	12.63
LECLAIR I D	S	9,400	163.94	.01		.01
RIVERTON VALLEY I D	S	5,827	134.62	.03	21.45	21.48
WORLAND AREA	S	1,710	246.90	.02		.02
CHEYENNE DIVISION						
ANGOSTURA UNIT	F	9,911	156.37		17.16	17.16
BELLE RIVER PUMP ASSOC	S	1,721	99.02	.74	24.28	25.02
RAPID VALLEY UNIT	S	7,800	113.23		.47	.47
FRENCHMAN-CAMBRIDGE						
FRENCHMAN-CAMBRIDGE I D	F	38,178	250.24	1.76	24.37	26.13
FRENCHMAN VALLEY I D	S	7,437	250.07	3.37	11.95	15.32
H&RW IRRIGATION DIST	F	9,737	221.36	1.12	11.07	12.19
GRAND DIV						
SHADEHILL UNIT	F	809	112.85	14.64	2.68	17.32
HEART DIVISION						
DICKINSON UNIT	F	198	121.21	2.02		2.02
HEART BUTTE						
LOWER HEART I C	F	2,474	229.01	1.81	.61	2.42
INDIVIDUAL PUMPERS	F	917	195.06	1.83		1.83
W HEART RIVER I D	F	1,575	130.97	2.32	.46	2.78
HELENA-GREAT FALLS DIV						
HELENA VALLEY UNIT						
HELENA VALLEY I D	F	13,867	102.42	.79	12.54	13.33
JAMES DIV						
KANASKA DIV						
ALMENA UNIT	F	4,520	230.69	1.57	16.52	18.09
MARIAS DIV						
LOWER MARIAS UNIT	F	1,409	164.02	.75		.75
MIDDLE LOUP DIV						
FARWELL UNIT	F	39,123	213.59	.90	21.29	22.19
SARGENT UNIT	F	10,312	181.78	.50	22.18	22.68
NO DAKOTA PUMPING DIV						
FORT CLARK UNIT	F	707	43.98		26.83	26.83
NORTH LOUP DIV	F	1,044	171.61	301.19	4.54	305.73
OREGON TRAIL DIV						
GLENDO UNIT-NE						
BRIDGEPORT I D	S	13,197	181.76	.29	4.26	4.55
ENTERPRISE I D	S	7,362	323.64	.11	12.50	12.61
1/ MITCHELL I D	S	12,125	323.56	2.30	13.00	15.30
GLENDO UNIT-WY						
BURBANK DITCH C	S	316	136.52	.18	18.67	18.85
LUCERNE CANAL&POWER C	S	3,411	198.05	.28	3.75	4.03
NEW GRATTON DITCH C	S	1,183	244.52	.22	.96	1.18
TORRINGTON I D	S	2,008	190.12	.14	8.55	8.69
SANDHILLS DIV						
AINSWORTH UNIT	F	26,915	234.02		13.78	13.78
SMOKY HILL DIV						
SOLOMON DIV						
KIRWIN UNIT	F	6,838	217.75	1.44	20.14	21.58
WEBSTER UNIT	F	4,168	177.70	2.35	24.41	26.76
THREE FORKS DIV						
CROW CREEK PUMP UNIT	F	4,398	212.60	.20	14.71	14.91
EAST BENCH UNIT	B	26,497	106.64		11.21	11.21
WIND DIVISION						
RIVERTON UNIT	F	36,616	188.58	.81	26.00	26.81
YELLOWSTONE DIV						
SAVAGE UNIT	F	1,971	357.50		20.24	20.24
SHOSHONE						
ELK WATER USERS ASSOC	S	3,557	240.33	.33	.78	1.11
FRANNIE DIVISION						
MONTANA LANDS	F	75	88.56	.31	10.00	10.31
WYOMING LANDS	F	13,664	162.19	.31	9.26	9.57
GARLAND DIVISION	F	31,602	308.50	.33	23.32	23.65
HEART MOUNTAIN DIVISION	F	29,449	219.36	2.07	15.33	17.40
LOVELL I D	S	9,411	240.80	.33	6.91	7.24
WILLWOOD DIVISION	F	10,235	317.15	.33	23.10	23.43
SUN RIVER						
FORT SHAW DIVISION	F	8,681	83.79		13.15	13.15
GREENFIELDS DIVISION	F	70,646	170.51		17.17	17.17

AGRICULTURE OPERATION AND MAINTENANCE COSTS AND GROSS CROP VALUES PER IRRIGATED ACRE - 1987

REGION, PROJECT	SUPPLY	IRRIGATED ACRES	GROSS CROP VALUE PER IRRIGATED ACRES	AGRICULTURAL O&M COST PER IRRIGATED ACRE ($)		
				BUREAU	WATER USER	TOTAL
TRINIDAD	S	16,092	163.15	4.39		4.39
1/ WATER SUPPLY&STORAGE C	S	37,425	329.13		8.78	8.78
1/ WEST BENCH I D	S	5,382	120.77		1.31	1.31
1/ WHITNEY I D	F	6,947	89.80		6.17	6.17

1/ PROJECT CONSTRUCTED OR REHABILITATED UNDER THE SMALL RECLAMATION PROJECTS ACT OF 1956, P.L. 84-984.
2/ THIS LEGAL ENTITY HAS A SMALL RECLAMATION PROJECTS LOAN IN ADDITION TO A SERVICE REPAYMENT CONTRACT.
3/ PROJECT CONSTRUCTED UNDER THE DISTRIBUTION SYSTEM LOANS ACT OF 1955, P.L. 84-130.
A/ ESTIMATED
B/ INCLUDES TRANSPORTATION LOSSES
C/ INCLUDES OPERATIONAL SPILLS

SUPPLY CODE
F - FULL WATER SUPPLY
S - SUPPLEMENTAL WATER SUPPLY
B - BOTH FULL & SUPPLEMENTAL

JUST ADD WATER

by David J. Ford

The words on labels tell this tale,
In recipes, in ads by mail,
And chances are, at work or play,
You'll see these famous words today -
Just add water.

You'd be surprised how many things
Are dry and useless till one brings
The magic liquid known to all;
You use it when you heed the call -
Just add water.

To illustrate and prove this thought,
Remember all the food you've bought
On which was printed, clear and bright,
Instructions that make cooking light -
Just add water.

You now can buy, in many makes,
Dried fruits, or soups, or tasty cakes;
To powdered milk and frozen juices,
To products with a thousand uses,
Just add water.

Imagine for a minute, please,
An arid wasteland, bare of trees;
This could be farmland, rich and good
And quite productive if we could
Just add water.

What turns cement into concrete?
What changes seed to golden wheat?
No other words now known to man
Can answer that; but these words can:
Just add water.

GPO 857-975

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.